

HYDRODYNAMIC LOADING ON OFFSHORE STRUCTURAL ELEMENTS DUE TO BIOFOULING

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ABSTRACT

Marine biofoulers is the collective term for organisms growing on man-made structures placed in marine environment. As a result of biofouling several design parameters such as structural loading, hydrodynamic loading etc. are altered. In addition, biofouling may alter the resistance of structural materials against corrosion and boring. Growth due to fouling may also cause hindrance for inspection of marine structures.

In the current study a theoretical analysis is carried out to find the relative effect of biofouling on the hydrodynamic loading on structures. For this purpose a typical offshore platform in the Bombay High region is considered. The percentage increase in the hydrodynamic loading is calculated for various sizes of members and marine fouling thicknesses using a semi-empirical analysis. The results of analysis show that biofouling can cause significant increase in hydrodynamic loading.

INTRODUCTION

Man's endeavours to exploit ocean resources have increased considerably in recent years. Offshore drilling, ocean mining, desalination, offshore metallurgy, alternative food and energy resources are some of the areas of ocean engineering which have registered rapid progress. The increased activities are in keeping with the demand for a host of materials, equipment and facilities which can withstand the rather hostile and aggressive marine environment. Several factors merit consideration before a material is recommended for ocean service. These include: structural strength, predicted life, knowledge of uncertainty and thorough understanding of the behaviour of the material against the factors causing its deterioration. It could be due to the impact of physico-chemical parameters as well as interaction with various organisms in the surrounding environment. Important among the deterioration processes are the phenomena of biofouling, corrosion and destruction by boring organisms. These processes have received

considerable attention because they affect the economics of shipping, transport and stability of the structures, which in turn govern the industrial growth and economic prosperity of nation.

The process of biofouling, as is well-known, results due to the attachment of various organisms, to any man-made structure exposed to marine environment. The fouling assemblage comprises of plants as well as animals, which could be microscopic or macroscopic in size.

Microfouling, also known as slime or primary film, is the first stage of fouling of a surface exposed to sea water. They comprise of bacteria, diatoms, microscopic algae and protozoa. Microfouling although unimportant from the structural loading point of view, is quite significant because it influences the attachment of macro-organisms and alters corrosion behaviour. Some of the organisms present in the slime film are reported to be very resistant even to toxic materials (Marine Fouling and Its Prevention, 1952).

Macrofouling organisms are generally divided into two major types, viz., soft fouling and hard fouling. Soft fouling, also called grass fouling organisms include all plant species and some animal species such as sponges and sea anemones. They are flexible and have a specific gravity of about 1.3 to 1.4. They are important from structural loading point of view and lead to problems associated with strength of structures.

The fouling organisms cause physical damage to the structural materials by directly attacking them. Some fouling organisms can penetrate through coatings and in some cases the part of metal comes off while removing fouling organisms. Bacteria may decompose paints on steel structures or alter their activity, reducing their effectiveness against corrosion (LaQue, 1972). Barnacles can damage paints when they are either alive or dead. Some types of clams, bivalves and ascidians can bore into concrete upto 40 mm depth (Snow, 1986). However, certain macrofouling organisms like barnacles attach themselves on concrete structures by means of a substance called cyprid cement (Crisp, 1972) and protect the reinforcement from corrosion by increasing the alkalinity of the concrete (Patil et al, 1986).

EFFECT OF BIOFOULING ON HYDRODYNAMIC LOADING

In the design of marine structures, the major factors taken into account are the effect of waves. Millions of waves hit a marine structure every year. Each of these waves exerts a force on the structure, depending mainly on the wave height, the wave period and the direction of wave motion. Out of the several effects caused by wave action, the most important effect on the structures is the hydrodynamic loading. It results from the impact of ocean waves on structures. This wave force can be evaluated by using Morison's equation for a vertical cylindrical structural element (Shore Protection Manual, 1977):

$$F = \frac{\rho}{2} \cdot C_d \cdot D \cdot u |u| + \rho \cdot C_m \cdot \frac{\pi}{4} \cdot D^2 \cdot a \quad \dots \quad (1)$$

where,

F = wave force per metre of the structure
 ρ = density of sea water (kg/cu.m)

D = member diameter
 u = waver particle velocity
 a = du/dt = water particle acceleration
 C_d = drag coefficient
 C_m = mass or inertia coefficient.

Equation (1) consists of two components viz. the drag force component and the inertia force component. The drag force is dependent on the water particle velocity, while the inertia force is dependent on the water particle acceleration. As both water particle velocity and acceleration are dependent on wave height and period, the drag and inertia components depend upon the ratio of wave height to member diameter. For small waves or large diameters, the inertia force dominates while for the reverse conditions, the drag force predominates. This reliance may be expressed approximately by Keulegan-Carpenter Number (K), defined as the ratio of member diameter (D) to the wave height (H) (Heaf, 1981):

If $D/H > 0.2$, inertia force predominates.
 If $D/H < 0.2$, drag force dominates.

Biofouling on marine structures increases the effective diameter of the structural members and also increases the surface roughness. The increase in the effective diameter increases considerably the hydrodynamic loading. The thickness of marine growth varies from place to place and with depth. In the absence of a detailed information, Freeman (1978) has suggested that the thickness of marine growth may be assumed as 250 mm, while designing marine structures, in general.

The increase in surface roughness due to biofouling is very difficult to quantify, because of the variation in the degree of roughness caused by different fouling organisms. Many investigators have tried to correlate the drag coefficient C_d with the relative roughness (k/D) where, k is the roughness height and D is the member diameter. Sarpkaya (1981) conducted laboratory experiments on 7" and 8" cylinders with relative roughness ranging from 1/200 to 1/800. He gave a plot of the wave force coefficients C_d and C_m versus Reynolds Number, for marine roughened cylinders (Fig 1).

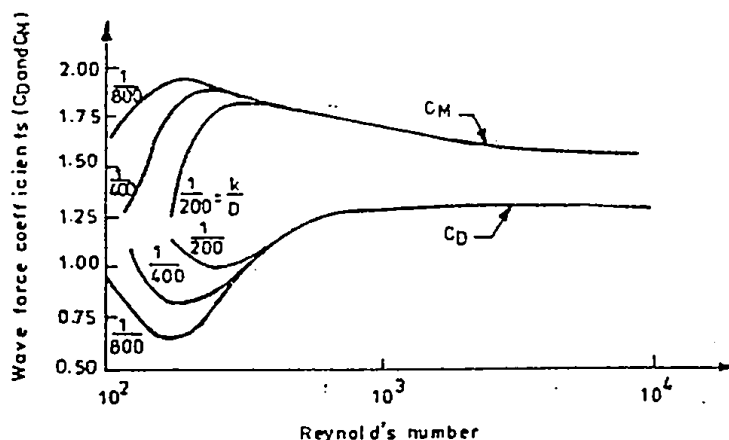


FIG.1 RECOMMENDED VALUES OF C_D AND C_M FOR ROUGH CYLINDERS (Sarpkaya, 1981)

Heideman and George (1981) tried to correlate C_d with relative roughness. They stated that a small relative roughness of 0.3% causes a drastic increase in the values of C_d . They quoted a range of values for C_d between 0.8 and 1.2 for the marine growth with relative roughness between 0.07% and 4%. These figures were for hard fouling. However, under actual field conditions, both hard and soft fouling co-exist. The effect of soft fouling on the wave force coefficients are not known. Heideman and George (1981) suggested that cylindrical structural members with both hard and soft fouling will have a lower drag coefficient than the members with only hard and rigid fouling. This statement was based on the argument that soft foulers give the member a more streamlined shape and greater flexibility.

Recently, Wolfram et al (1985) conducted laboratory experiments to evaluate C_d . The test cylinders were attached with various types of marine foulers (barnacles, kelps; hard mussels and sea anemones) separately. They were accelerated in static water, from rest to a predetermined terminal velocity by means of gravitational or buoyancy forces. Their results have shown that barnacle fouling gave a lesser value of C_d than mussel fouling. The C_d values for mussel fouling was between 0.75 to 0.8. The difference in C_d values between these two foulers were attributed to the relative increase in the mean cylindrical diameter and greater apparent roughness due to mussel fouling.

However, Shore Protection Manual (1978) has suggested the following values for C_d for super-critical Reynolds numbers ($Re > 1 \times 10,00,000$), which is the case for offshore structures.

Type of surface	Value of C_d
i) smooth surface with bitumastic	0.61
ii) bitumastic with soft and light fouling	0.88
iii) bitumastic with hard fouling	1.02

The effect of biofouling on the inertia coefficient C_m is difficult to assess quantitatively. The smaller the relative roughness, the larger is the maximum inertia coefficient. Heaf (1981) states that for larger diameter members, the effect of roughness does not influence the inertia coefficient substantially.

Depending on the range of Reynolds Number, Shore Protection Manual gives the following values for C_m .

$$C_m = 2.0 \text{ for } Re < 2.5 \times 1,00,000$$

$$C_m = 2.5 - Re/(5 \times 1,00,000) \text{ for } 2.5 \times 1,00,000 < Re < 5 \times 1,00,000$$

$$C_m = 1.5 \text{ for } Re > 5 \times 1,00,000$$

As stated above, the effect of biofouling on marine structures is to increase the effective member diameter and also the surface roughness so as to increase the hydrodynamic loading on the structure. The extent of increase depends on the thickness, nature and pattern of fouling. This investigation attempts to quantify the increase in hydrodynamic loading on account of biofouling.

DATA FOR ANALYSIS

In order to find the importance of loading generated by the presence of marine fouling, a typical offshore platform is analysed in the Bombay High area (Fig 2). In the area of analysis, the depth of water is approximately 75 m. The design significant wave height is 8.2m with a period of 9 seconds. The platform consists of members with diameters in the range of 0.4 m to 1.5 m. For convenience, the member diameters considered in the analysis are 0.4 m, 0.6 m, 0.8 m, 1 m, 1.2m and 1.5 m. The drag and inertia components of the wave forces are estimated by using the relations given in Shore Protection Manual(1977).

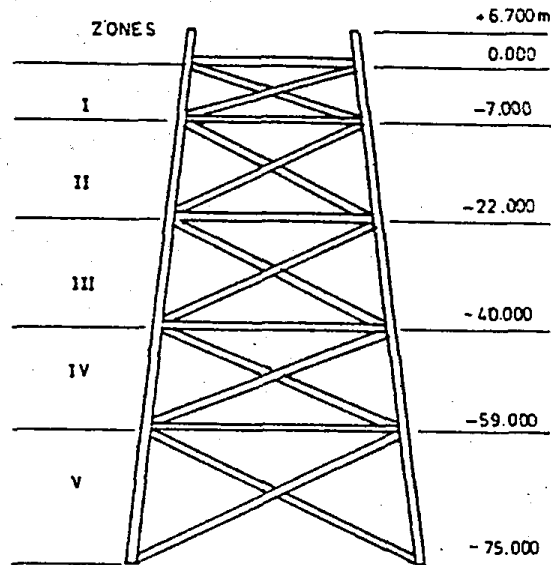


FIG. 2 SKETCH OF A TYPICAL OFFSHORE PLATFORM (BOMBAY HIGH)

In order to find the relative importance between the two effects of biofouling, viz., increase in effective diameter and surface roughness, it is assumed in one set of analysis that biofouling causes only an increase in the effective diameter, the increase in surface roughness being negligible. Similarly in another set of analysis, only the increase in surface roughness is considered, neglecting the increased member diameter.

EFFECT OF INCREASED MEMBER DIAMETER

The effect of increased member diameter due to fouling growth is evaluated for different values of D . The marine fouling thickness causing the increase in diameters are assumed to be in the range of 50-250 mm. As stated earlier the increase in surface roughness is neglected and so C_d turns out to be a constant. These values are shown graphically in Fig 3.

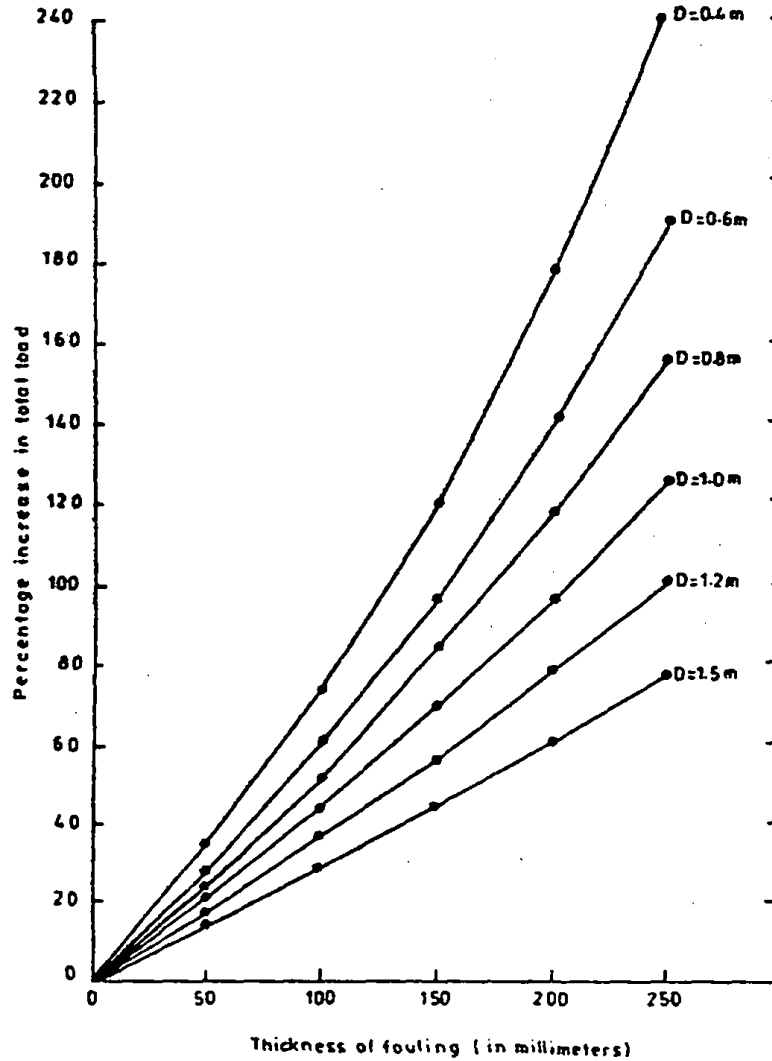


FIG. 3 PERCENTAGE INCREASE IN TOTAL LOAD DUE TO INCREASED FOULING THICKNESS.

EFFECT OF INCREASED SURFACE ROUGHNESS

The increase in surface roughness (and hence C_d) is indeed difficult to quantify. However, many authors (Sarpkaya 1981, Heideman and George 1981, Wolfram 1985, Shore Protection Manual, 1977) have accepted the range of values for C_d as between 0.6 and 1.0 (the former value for a smooth member without fouling). In the present analysis, for different values of C_d , the increase in total load is estimated, keeping the effective diameter constant. The results are presented in Table 1 and shown in Fig 4.

Table 1: Percentage increase in total load due to increased surface roughness ($C_d = 0.6$ for smooth surface)

Member diameter	Percentage increase in total load		
	$C_d = 0.75$	$C_d = 0.9$	$C_d = 1.0$
0.4 m	19.4	39.4	53.14
0.6 m	18.0	31.2	40.00
0.8 m	7.0	17.7	26.15
1.0 m	2.25	6.2	10.60
1.2 m	0.40	3.8	7.20
1.5 m	-	-	0.125

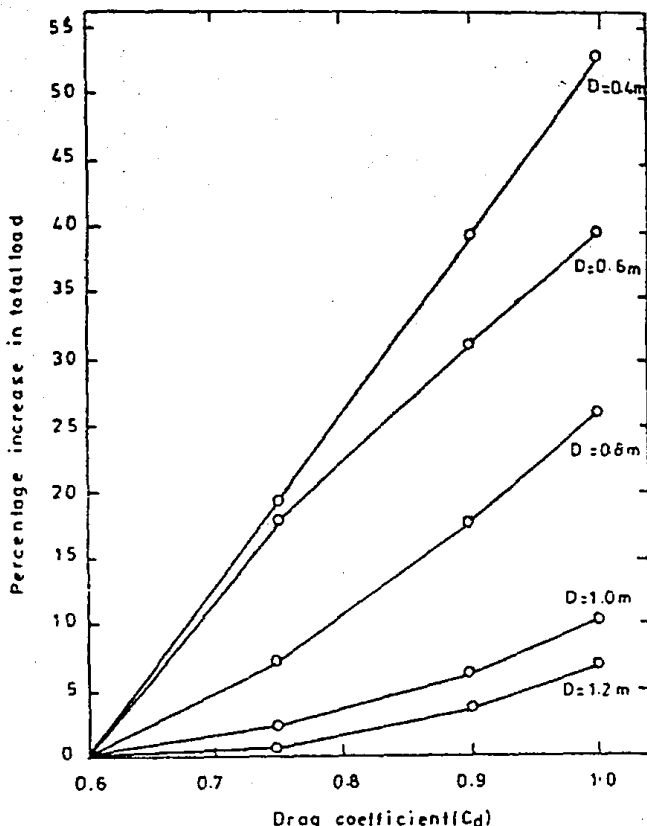


FIG. 4 PERCENTAGE INCREASE IN TOTAL LOAD DUE TO INCREASED SURFACE ROUGHNESS.

DISTRIBUTION OF TOTAL LOAD TO DIFFERENT ZONES

As stated above, the drag and inertia dominated regimes can be expressed in terms of Keulegan-Carpenter Number (Heaf, 1981), defined as the ratio of member diameter to wave height. Thus,

When $D/H \geq 0.2$, inertia force dominates
 When $D/H < 0.2$, drag force dominates.

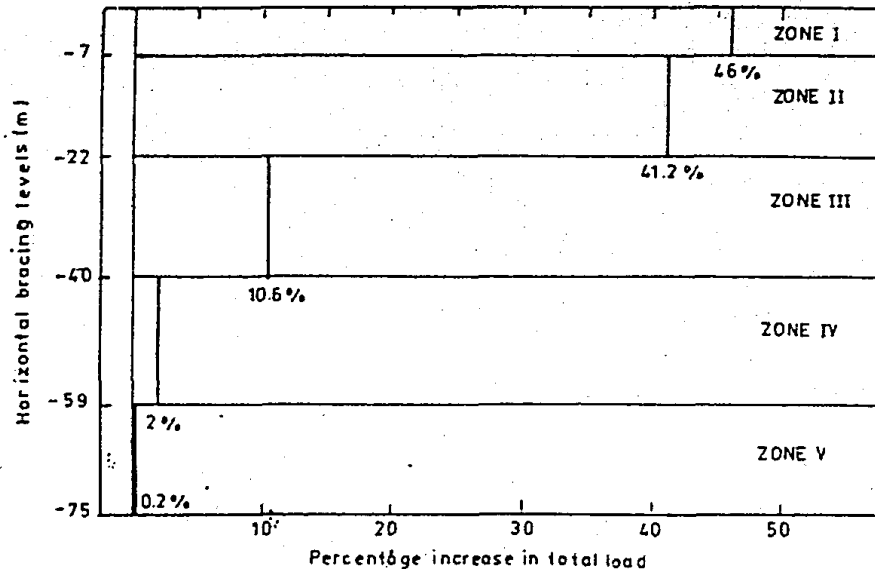


FIG. 5 PERCENTAGE OF TOTAL LOAD GENERATED AT EACH LEVEL OF A TYPICAL OFFSHORE PLATFORM.

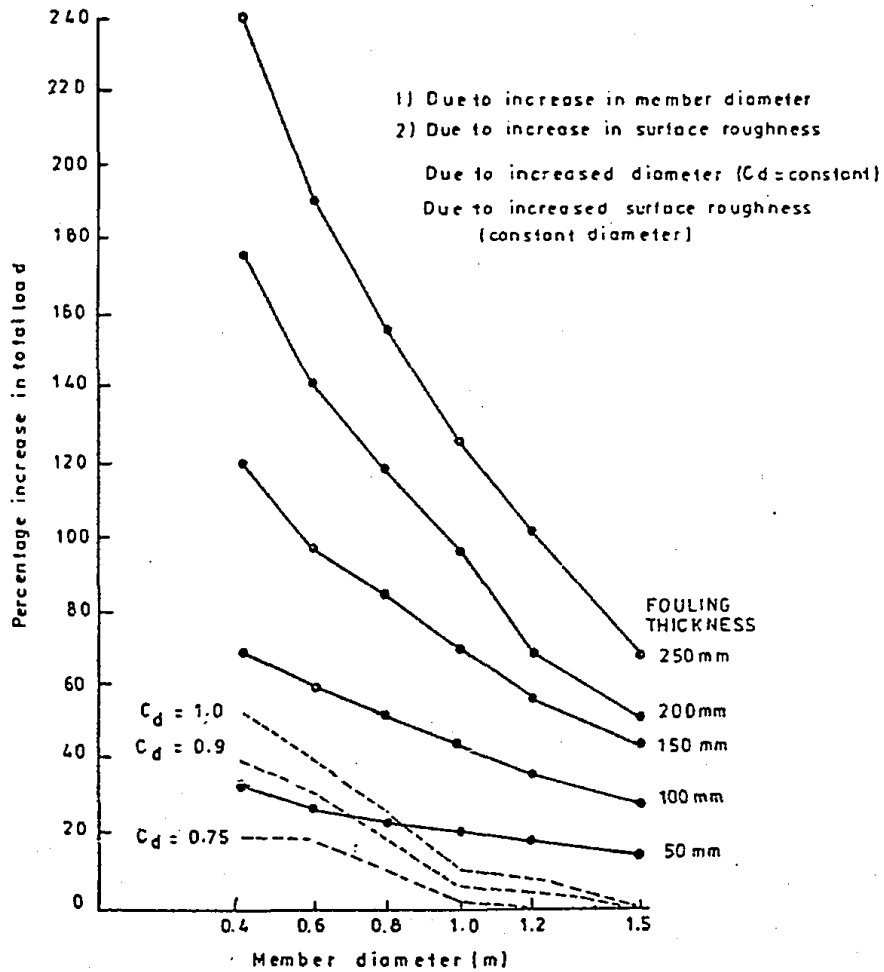


FIG. 6 PERCENTAGE INCREASE IN TOTAL LOAD DUE TO BIOFOULING.

For the typical Bombay High (Offshore) platform under consideration, the maximum member diameter is 1.5 m and the wave height is 8.2m.

$$D/H = 1.5/8.2 = 0.183 < 0.2.$$

This shows that for this situation drag force predominates. Hence, it is assumed in the subsequent analysis that the loading in each portion of the structure is proportional to the square of the velocity of the particles, the drag coefficient and the member diameter. Further, the stress in any member of the structure is

- i) due to local loading by the wave-induced forces on the member itself,
- ii) due to the overall deformation of the structure under the integrated load on the whole structure.

In the present analysis, the effect of only the local loading is considered.

The nature of wave motion is always such that the highest water particle velocities and accelerations are near the water surface. Hence, the highest local loading will be experienced near the mean water level and it decreases exponentially as depth increases. For the given offshore conditions, water particle velocities are calculated using the relation:

Horizontal water particle velocity

$$(u) = \pi H/T \cdot \cosh [2\pi/L(y+d)] / \sinh [2\pi d/L]$$

where,

y = depth below mean water level.

The values of u at different bracing levels are given below:

Depth below m.w.l. y(m)	Velocity u (m/sec)
0	2.86
-7	2.06
-22	0.98
-40	0.41
-59	0.18
-75	0

From the velocities, the forces generated at each level can be calculated and they are averaged for each of the zones. Thus, an estimate of the load generated in each zone can be calculated, the results of which being shown in Fig 5. This estimate enables assessment of the percentage increase in total load due to various thicknesses of fouling viz., 50 mm, 100 mm, 150 mm and 200 mm (Fig 6). For this, a suitable value of C_d is selected ($C_d = 1.0$ is taken in this case). The corresponding increase in total load for this value of C_d is taken from Table 1. To this, the increase in total load due to increased member diameter is added. This sum is now distributed to all the zones, proportional to their load-generating capacity.

For example, a 50 mm fouling on a 0.4 m diameter member causes an increase in the total load by 33.75%. On the same pile, the increased drag coefficient ($C_d = 1.0$) causes an increase in total load by 53.15%. The sum of these two values viz., 86.9% is now distributed to all the zones, proportionately.

The results are plotted in Figs 7 to 10.

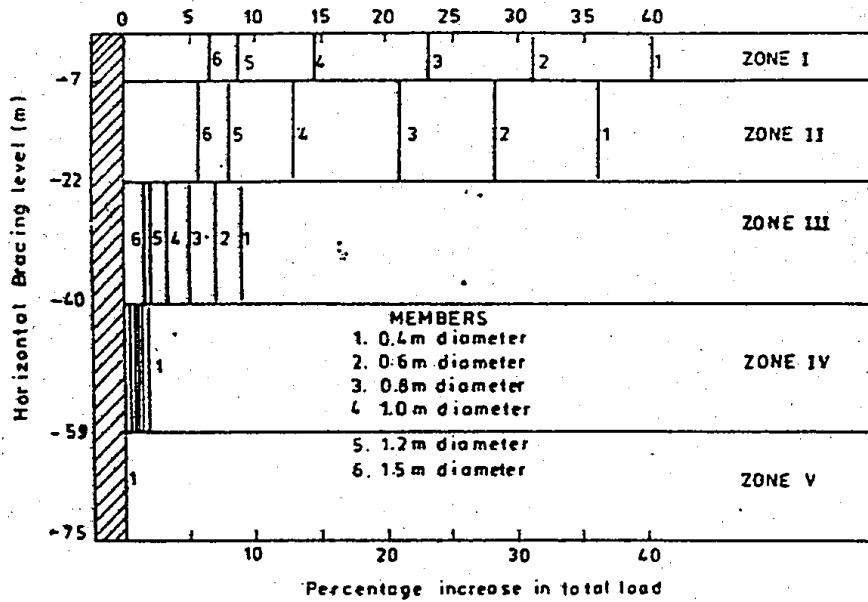


FIG. 7 INCREASE IN TOTAL LOAD DUE TO 50 mm FOULING THICKNESS.

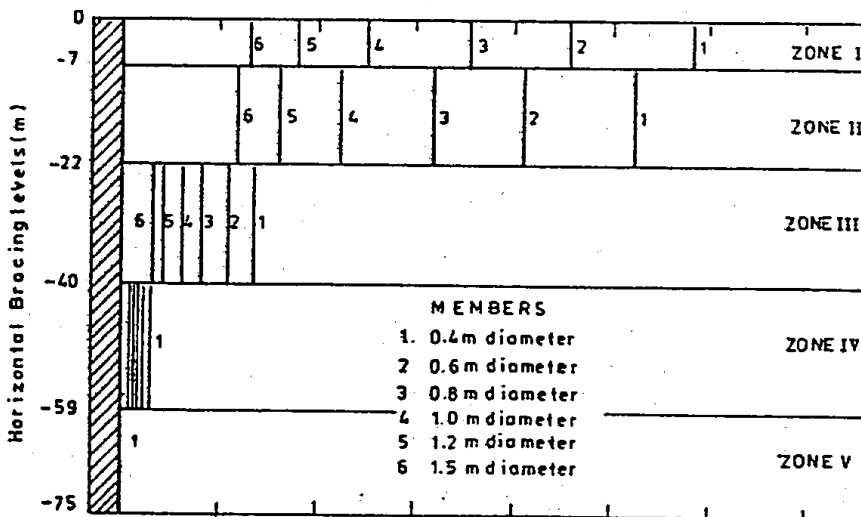


FIG. 8 INCREASE IN TOTAL LOAD DUE TO 100mm FOULING THICKNESS.

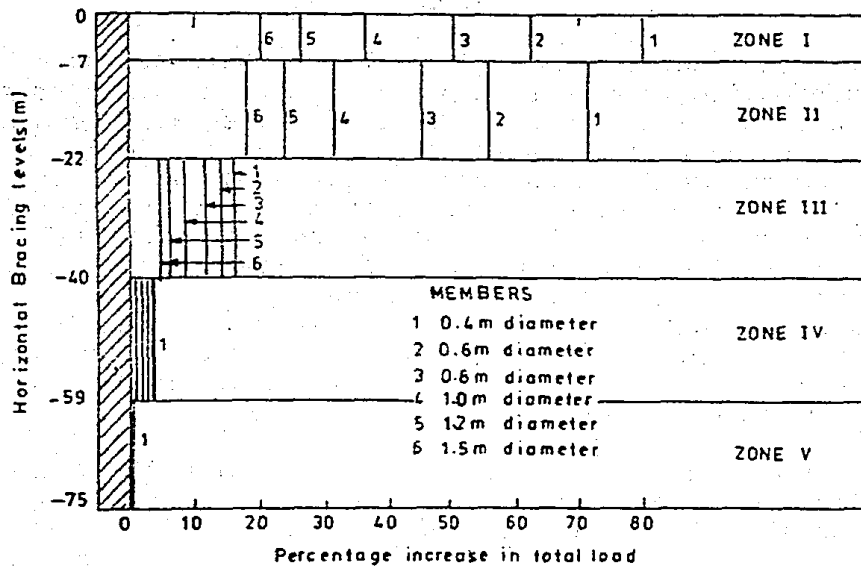


FIG. 9 INCREASE IN TOTAL LOAD DUE TO 150 mm FOULING THICKNESS.

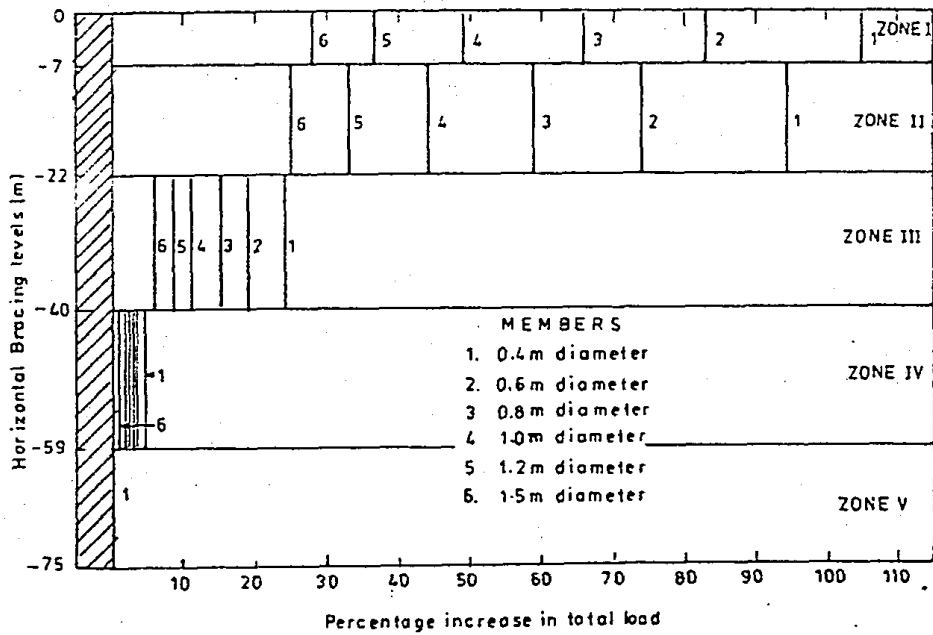


FIG. 10 INCREASE IN TOTAL LOAD DUE TO 200 mm FOULING THICKNESS.

DISCUSSION

From the figures 3 to 6, it is clear that the increase in load due to biofouling is more pronounced on smaller diameter members. Fig 3 also shows that as the member diameter increases, the increase in the total load tends to increase linearly with growth thickness. This is quite as expected because for any given marine fouling thickness, the relative increase in the effective diameter (k/D) is more for smaller diameter members. For the same reason, the increase in total load due to increased surface roughness is predominant on smaller member diameters (Fig 4). It can be seen that the effect of increased surface roughness is less significant as the member diameter increases. From the point of view of increased hydrodynamic loading due to biofouling, the effect of increased member diameter is much greater than the effect of increased surface roughness (Fig 6).

From Fig 5, it can be seen that a greater part of the load is generated near the mean water level. At depths below 22 m, the load generated is considerably reduced. This is because of the variation of water particle velocity with depth. As the depth increases, the velocity of water particles decreases exponentially, reducing to zero at sea bed. This leads to an important observation that the effect of biofouling in increasing the hydrodynamic load is significant only in the upper zones of fouling. But in our analysis, we have considered only the increase in local loading, due to fouling growth. However, loads (and hence stresses) are also induced due to the overall deformation of the structure under the integrated load on the whole structure. According to ~~Heaf (1981), about 40% of the total load generated at the splash zone is due to local loading and the remaining 60% being due to structural loading.~~ As the depth increases, the structural loading increases exponentially to 99% of the total loading at sea bed. Even with this estimate, it can be seen that the effect of increased hydrodynamic loading due to biofouling is more significant only in the splash zone and upto about 22 m depth.

CONCLUSIONS

- i) Marine growth can lead to a significant increase in the hydrodynamic loading on the structure, both overall and local loading.
- ii) Predominant increase in hydrodynamic loading due to biofouling is noticeable from mean sea level down to a depth of about 22 m. Hence cleaning operations will be beneficial, if concentrated within this depth.
- iii) Fouling growth is thicker and denser on horizontal members than on vertical members. Hence, greater part of the load generated by biofouling is caused by the bracing members, followed by the main legs of offshore structures.

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